Demonstration of a High Power, Wideband 220 GHz Serpentine Waveguide Amplifier Fabricated by UV-LIGA

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***Abstract*—We present the hot test results of a 220 GHz, serpentine waveguide vacuum electron amplifier showcasing a novel embedded monofilament microfabrication technique based on UV-LIGA. The instantaneous operating bandwidth exceeds 15 GHz and the small signal gain of the circuit is over 14 dB. By varying the voltage slightly, an operating bandwidth of almost 40 GHz is realizable with a minimum circuit gain of 7 dB across the band. A maximum power of just over 60 W was obtained at the output flange of the device, corresponding to a power of almost 80 W generated in the circuit.**

I. Introduction And Background

Ultraviolet photolithography techniques along with copper electroforming (collectively, UV-LIGA) are being developed at the U.S. Naval Research Laboratory in order to span the spectrum from under 100 GHz through 1 THz [1-3]. With use of a Patent-Pending embedded polymer monofilament UV-LIGA technique invented at NRL [4], 3D all-copper structures have been demonstrated that allow arbitrarily small beam tunnels to be fabricated to arbitrary length along with slow-wave amplifier circuits. These techniques are being demonstrated at W-band (95 GHz), G-band (220 GHz), and 670 GHz to date.

II. Amplifier Design

The serpentine waveguide (SWG) amplifier is designed to operate from a single, round 11.7 kV electron beam; operating parameters are listed in Table I [5]. Figure 1 shows various features of the final circuit both before and after brazing, the body assembly of the tube and a photo of the final tube during hot test. The vacuum windows are made from BeO and exhibit over 20 GHz bandwidth at below -20 dB reflection [6]. Using a 218.4 GHz EIK and a 214 GHz EIO as drivers, over 60 W output power is expected from the tube circuit.

III. Circuit Fabrication & Testing

To create reliable, high vertical aspect ratio serpentine features as required, a UV-LIGA technique was employed in two layers. Polymer monofilaments embedded in the SU-8 photoresist were used in the second layer in order to hold the shape of the electron beam tunnels while the ultraviolet passed through a lithographic mask to create the serpentine patterns [7-9]. After the SU-8 features have been formed around the polymer filament, the wafer is placed in a copper electroforming bath. The electroformed copper is ground to

TABLE I: Amplifier Operating Parameters

Parameter	*As-fabricated*
Beam voltage	11.7 kV
Collected current	105 mA
Beam transmission	>91%
Beam tunnel diam.	183 μm
Small signal gain	14 dB
Bandwidth	15 GHz
Max power out	68 W (expected)
Number of gaps	64

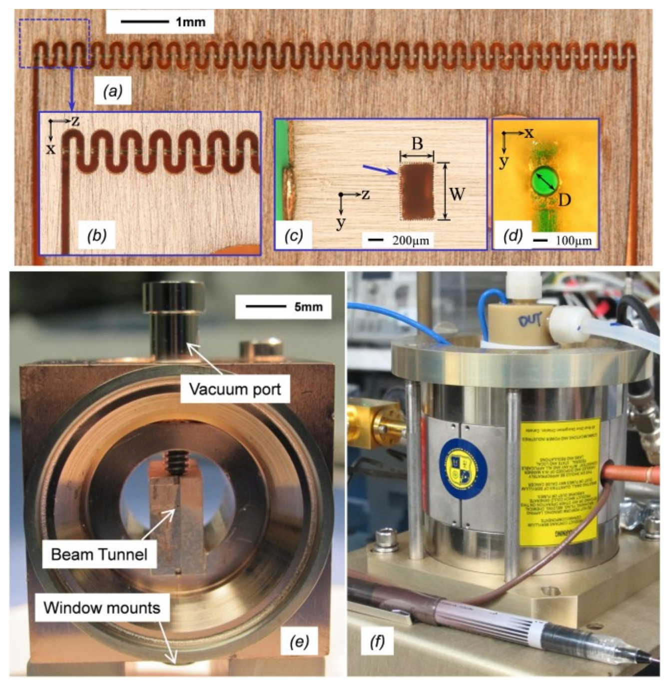

Figure 1. (a) Micrograph of completed circuit, and (b) zoomed view with 0.0072 inch diameter gage pin installed in beam tunnel. (c) View of completed input waveguide. (d) View of beam tunnel entrance. (e) Final brazed circuit assembly into tube vacuum body. (f) Final tube under hot test.

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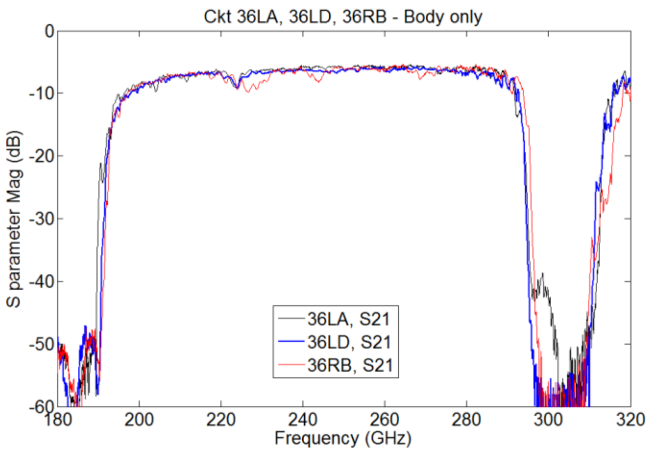

Figure 2. Comparison of S_{21} measurements of three circuits from wafer #36 exhibiting excellent match in frequency response. Note: S_{21} values shown include 2.9 dB of total losses in external tapers and waveguides.

thickness and polished, followed by a molten salt bath to remove the SU-8. After dicing to size and final lapping to thickness, the circuits are enclosed by brazing a flat cover piece on top.

Figure 2 shows cold test measurements for three circuits from the same wafer (50% yield) that exhibited near matches in frequency response. A small ripple at 223.5 GHz is evidence of a stopband beginning to appear at the $3\pi/2$ operating point. The achieved fabrication tolerances and beam tunnel alignments will be discussed.

IV. Hot Testing

Figure 3 shows the experimentally measured small signal gain profiles over broad bandwidth along with simulations in the NRL GPU code NEPTUNE [10]. The instantaneous bandwidth exceeds 15 GHz, and the small signal gain of the circuit itself exceeds 14 dB. As predicted, the usable bandwidth of the device can be quite large at lower beam voltage; a total usable range of approximately 200 GHz to 240 GHz is accessed by tuning the voltage over a 500 V span. At the tested voltages, the electron beam transmission is about 91% due to the electron beam being slightly enlarged relative to the beam tunnel.

Large-signal testing of the tube produced a maximum output power at the tube output flange of just over 60 W at 214.5 GHz at a beam voltage of 12 kV, which corresponds to almost 80W generated by the circuit.

V. Acknowledgement

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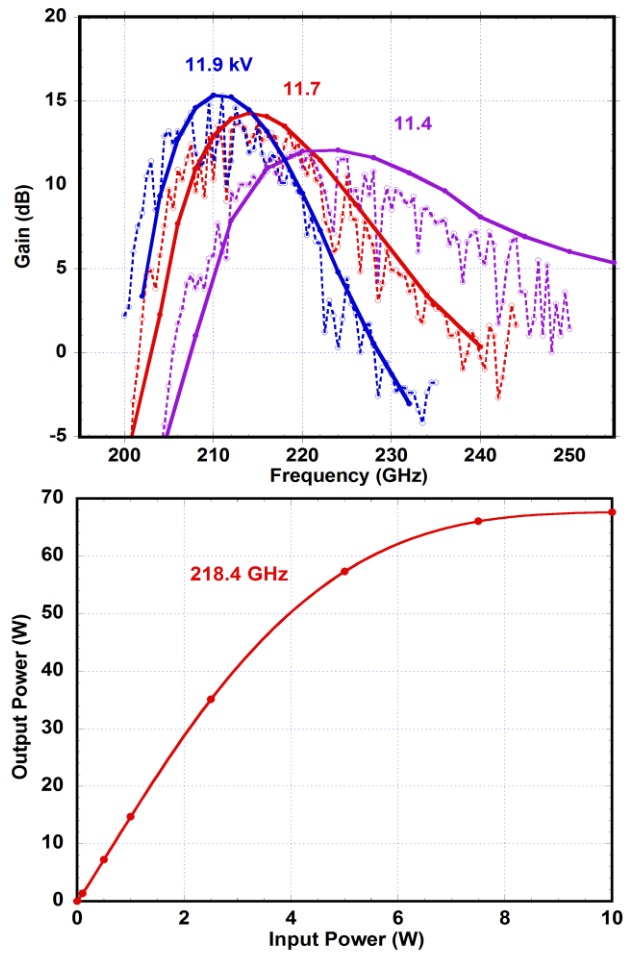

Figure 3. (top) Small signal gain of the circuit at three voltages (dotted) along with simulations in NEPTUNE. (Bottom) Predicted power drive curve showing over 60 W saturated using NEPTUNE.

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